

THE FUTURE OF TRANSPORTATION: AUTONOMOUS VEHICLES

ITS EFFECT ON SHIFTING LAND USE PATTERNS AND THE
CHALLENGES THAT WE CAN EXPECT TO FACE
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1 INTRODUCTION —

United States has long been known to be one of the top contributors to the carbon footprint of the world, ranking only second behind China. Although a lot of policies have been implemented in the past decade or so to bring the emission levels and energy consumption under control, there is still a lot that can be done in this area.

Transportation is said to be one of the major contributors to Greenhouse Gases. With new technologies coming up, we are noticing a shift from conventional automobiles to electric and autonomous vehicles. They promise more environment friendly operations, safety, and reliability. Even though they are being hailed as the next best thing in the world of automobiles, people are hesitant to make the switch due to limited information available at this date.

This paper attempts to study the extent to which such vehicles will aid to emission reduction efforts, and how that will impact road safety, air quality and the built environment in a major urban area.

2 LITERATURE REVIEW —

According to the latest US Environmental Protection Agency report, the transportation sector accounted for about 26% of the greenhouse gas emissions in 2014, second in place only behind the electricity sector(US EPA, n.d.). Vehicle cars and passenger trucks accounted for roughly 83% of this. (Zhao, Onat, Kucukvar, & Tatari, 2016).

Increasing concerns over the ill effects of this phenomena has led to the implementation of various policies, including a climate action plan implemented by President Obama that seeks to reduce 17% of the total CO₂ levels by 2020 (Park, Lim, Egilmez, & Szmerekovsky, n.d.)

An analysis done on the environmental efficiency of the transportation sector in the country showed that only four of the fifty states (Alaska, Illinois, Nebraska and Vermont) had scores above the measured threshold (Park et al., n.d.). Most of the GHG emissions in the environment are generated in the urban areas (Jiang, Ma, & Zhou, n.d.) due to the higher population, traffic congestion, vehicle characteristics and complex urban geometry (Mishra, Shukla, Parida, & Pandey, 2016). The approach to controlling for the CO₂ emissions, fuel consumption and emission reduction from the transportation sector is coordinating the “three-leg stool”, which are fuel types, fuel efficiency and VMT (Ding, Wang, Tang, Mishra, & Liu, n.d.). In this paper, we’ll be examining the impacts of future vehicles on the first two.

There is a big health factor associated with the above-mentioned emission levels. Exposure to airborne pollutants has long been associated with increase in mortality rate and hospital admissions due to respiratory diseases. These have been found in both short term and long term studies (Brunekreef & Holgate, 2002). Both ozone and fine

particulate matter (PM_{2.5}) in ambient air contribute to bronchitis and asthma, and might even be a reason for cardiovascular mortality. Not only does asthma affect 8.2% of U.S. citizens, but recent estimates say PM_{2.5} is responsible for 63,000 to 88,000 premature deaths every year. On road vehicles account for 26% of VOCs and 35% of NO_x emissions. Most of these come from short car trips in the urban regions (Grabow et al., 2012). Tighter air quality regulations have positively affected overall air quality, but ambient air quality is still a big concern. The levels of ambient noise created on road junctions have also been shown to have adverse effects on health. They contribute to a number of problems including cardiovascular mortality, sleep disturbances, cognitive problems in children, diabetes and mental health issues. This also generally affects the low income individuals and minorities that are usually located in the areas most polluted by traffic (Khreis et al., 2016). Any reduction achieved in emissions would be extremely helpful in bringing down the level of ambient air pollution, thus helping reduce the number of cases of hospital admissions due to adverse effects of traffic pollution.

To reduce the ill effects caused by ambient air pollution, the most important factor that has to be controlled in the transportation sector is the urban tailpipe emissions. The main factors that usually affect these are the speed and acceleration of the vehicles. CO₂ is more dependent on speed while NO_x and PM levels are subject to acceleration behavior (Jiang et al., n.d.). Driving patterns account for a lot of the emissions. Frequent acceleration and deceleration has shown to give lower fuel efficiency in delivery trucks (Zhao et al., 2016). Another good approach to dealing with the issue at hand is encouraging carpooling. High passenger occupancy automobiles like small sedans and SUVs have shown to lower per passenger trip emissions for CO₂, NO_x, and PM_{2.5} for

the trip range examined (H. Liu, Xu, Stockwell, Rodgers, & Guensler, 2016).

Households that joined car sharing increased their GHG emissions by gaining access to automobiles, but the remaining households joining reduced theirs by giving up their vehicles and driving less. Overall, the decrease was much higher than the increase, proving that car sharing does help reduce emissions as a whole (Martin & Shaheen, 2011). Greenhouse gases like carbon monoxide are supposed to be 20% more relevant than CO₂ for climate change and, therefore, the long term effects of such gases needs to be considered as well (Reichert, Holz-Rau, & Scheiner, 2016).

Even though it's being called the transportation of the future, alternative fuel vehicles have been unsuccessful in replacing diesel and gasoline vehicles in the past. Recent years have shown a change in this pattern with the introduction of plug in electric vehicles (PEVs), both "pure" battery and hybrid. "Pioneers", or the people who are more geared towards the implementation of climate change policies, prefer purely electric vehicles, but even potential future buyers are interested in the idea of a mixed hybrid vehicle (Axsen, Goldberg, & Bailey, 2016). In heavier delivery trucks, electric models have shown a lot of promise with respect to reducing tailpipe emission and increasing fuel efficiency. However, since the source of electricity generation is mostly coal based, the life cycle emissions are higher, making hybrid vehicle a better choice than others. If electricity generation sees a shift from coal to natural sources, electric vehicles have the potential to become the most fuel and emission efficient (Zhao et al., 2016). A drawback with electric models is the long charging times and short range. At present, Battery electric vehicles (BEVs) only have an average driving distance of 150kms, with the longest range being 420kms for the new Tesla Model S. In comparison, a normal

vehicle can cover a distance of over 800kms on one tank of gasoline. This range is further affected by temperature changes which can increase energy consumption requirements (Asamer, Graser, Heilmann, & Ruthmair, 2016).

People are now much more open to accepting new vehicle technology if it can help reduce traffic safety incidents and road congestion. Connected and autonomous vehicles (CAVs) have the potential to reduce 90% of the crashes that result from driver error. A survey conducted in Austin, Texas showed that respondents consider lower number of crashes to be the biggest advantage of autonomous vehicles. However, their biggest concern is equipment failure (Bansal, Kockelman, & Singh, 2016). The new vehicle technology will also aid travel for the disadvantaged groups and the elderly, thereby increasing the light duty VMT of riders 19 and older by 14%. (Harper, Hendrickson, Mangones, & Samaras, 2016).

Modifying travel behaviors may show more effect on reduction of fuel consumption and emissions than new technologies. An FEOS system showed reduction in consumption of fuel by 22-31% in acceleration conditions and 12-26% while decelerating (Wu, Zhao, & Ou, 2011). Autonomous vehicles may soon replace automobiles as a daily mode for transportation. With companies such as Google and Audi developing their own stereotypes for testing, that future may not be very far. Navigant Research estimates that 75% of all light duty vehicles sold by 2035 will be autonomous capable. Therefore, we need further studies on how such a major change will impact health and safety of the general public (Bansal et al., 2016).

Fully automated vehicles may be a long term goal, however, and introduction of semi-automated vehicles seems much more likely in the near future. An analysis conducted on a traffic flow which contained mixed manual and semi-automated vehicles showed that introduction of the newer vehicle technology helped smooth traffic flow and improved air pollution levels without any adverse effects on the flow rate (Bose & Ioannou, 2003). Not only was the time required to process a standing queue of vehicles at signalized intersections reduced by 25% (Le Vine, Liu, Zheng, & Polak, 2016), a lot of emergency situations simulated proved to demonstrate that Autonomous intelligent cruise control (AICC) leads to much safer driving conditions (Ioannou & Chien, 1993).

A fuel economy testing of autonomous vehicles showed that if the AVs are designed considering fuel efficiency, consumption rates may be lower by as much as 10%.

Controlling acceleration and deceleration rates is one of the ways to achieve this (Mersky & Samaras, 2016). Connected vehicles with a speed advisory system (SAS) can help lower fuel consumption and improve ride comfort by idling less at red lights. They also benefit other conventional vehicles on the road, with better results gained as the percentage of SAS-equipped vehicles goes higher. This is achieved with little compromise to average traffic flow and travel time (Wan, Vahidi, & Luckow, 2016).

All the above listed advantages are increased if we consider a case of shared autonomous vehicles. Each SAV can help replace around eleven conventional vehicles, although it does add up to 10% more travel distance to non-SAV trips. Overall emissions impacts are still on the positive side (Fagnant & Kockelman, 2014). We may even be able to affect land use patterns by reducing parking demand by about 90% (Zhang, Guhathakurta, Fang, & Zhang, 2015). Studies show that factors such as travel

cost, time and waiting periods may be important in determining if SAVs will be adopted. Young individuals and people with multimodal travel patterns are more like to adopt it (Krueger, Rashidi, & Rose, 2016). If we consider a step above this, a shared electric autonomous vehicle (SAEV) is said to be able to serve 96-98% of trip request with average wait times only between 7 to 10 minutes. However, they do add an additional 7.1 to 14% travel miles due to the “empty travel” phase required for vehicle recharge (Chen, Kockelman, & Hanna, 2016).

Although the above data looks very promising in the coming future, we may have to face problems if we look at it from a long term approach. People’s travel behavior may tend to change due to the flexibility an autonomous vehicle offers. AVs will lead to better outcomes if the current travel patterns are maintained. If ridership increases (which it is expected to), it can lead to more congestion and may even lead to public travel becoming obsolete. (Gruel & Stanford, 2016).

3 IMPACT OF THE TRANSPORTATION SECTOR —

3.1 TRANSPORTATION AND AIR QUALITY -

As of 2014, the transportation sector is responsible for 26% of the total greenhouse gas emissions in the United States. This is due to the burning of fossil fuels for our vehicles, with over 90% of the fuel used in transportation coming from petroleum based sources (US EPA, n.d.). The amount of energy consumed by the sector is expected to increase further in the coming years (Park et al., n.d.). States have a responsibility to ensure that their emissions stay within the required range. An environmental efficiency study conducted over a period of 2004 to 2012 showed that only four of the fifty states (Alaska, Illinois, Nebraska and Vermont) were found to be energy efficient. Texas was the most inefficient and most states ranked below 0.64 on the scale, suggesting that they all have considerable room for improvement (Park et al., n.d.).

One way of going about reducing the impact is through increasing fuel efficiency of vehicles. During a vehicle's operation phase, 21. – 34.1% of the total fuel consumption happens during non-productive times such as idling (Zhao et al., 2016). The frequent acceleration and deceleration also lead to lower fuel efficiency (Zhao et al., 2016).

Transportation and climate change are not just linked to one another, but they also indirectly affect human behavior and mode choices. Not only does an increased level of emissions lead to climate change, but people tend to take longer non-work trips in warm weather (Precipitation and snow discourage people from taking long trips). A 5°C increase in mean temperature shows an increase of 6.8% in emissions (C. Liu, Susilo, & Karlström, 2016).

The above stated observation is also highly dependent on other factors such as demographics and geography. A comparison of VMTs in urban and rural populations in Germany concluded that for daily trips, rural areas have higher levels of emissions due to increase trip distances. This was offset in urban areas only through frequent long distance 'escape' trips that is supported by the city lifestyle, but this is overshadowed by the fact that long distance trips account for only 21% of all CO2 emissions, with 93% of CO2 emissions by cars happen on daily trips. This shows us that daily trip distance is a big factor to consider if a reduction in GHG emissions levels is to be achieved. (Reichert et al., 2016). Other factors such as household income, employment status, education level, etc are also extremely significant in contributing to the choice of mode for traveling and the frequency of trips.

3.2 TRANSPORTATION AND THE BUILT ENVIRONMENT -

It is not just air quality that is affected by the transportation sector. Being the lifeline of a city means that transportation plays a big role in defining a city's character. There have been a lot of studies conducted into the relationship between the built environment and transportation. Dense areas have shown to encourage short-distance trips, and an increase in biking and pedestrian activity, leading to lower emission rates (Reichert et al., 2016). The shorter distances and better street connectivity also encourage use of alternative modes. This is further encouraged due to the lack of parking spaces in compact urban environments. The further away a person lives from a Central Business District, the more likely it is that they'll own a car, due to the lack of transit facilities in their area (Ding et al., n.d.).

Apart from road capacity, infrastructure and amount of parking spaces, a big factor that also encourages people to drive more is availability of parking at the workplace. In fact, car use almost doubled where employees could pay for parking monthly instead of on a daily basis (Christiansen, Engebretsen, Fearnley, & Usterud Hanssen, 2017).

Combining that with an increased mixed use development where there is a good job-housing balance, higher street density, and reduced block sizes, will help reduce trip distances which would move people towards choosing alternative modes of transportation. This would, in turn, have a direct impact in mitigating CO2 emissions (Cao & Yang, n.d.). This is not to say that the density itself should not be kept in check. After a point, increasing density starts to have a negative correlation to the distance travelled. This can be seen through examples of developing countries such as India. In such cases, demographic variables such as income, vehicle ownership, etc took over as the most significant in deciding trip mode choice (Manoj & Verma, 2016).

3.3 TRAFFIC SAFETY -

It is not just the environment that undergoes harm due to traffic conditions. Pedestrians account for 11% of motor vehicle collision fatalities. Increasing mixed used development has its own disadvantages if not executed properly. Denser developments would most definitely encourage pedestrian activity. If the traffic in such areas is not kept in check, chances of these fatalities increasing is very likely. If done right, such environments can greatly benefit human health by reducing motor collisions, concentrated air pollution and increasing physical activity (Wier, Weintraub, Humphreys, Seto, & Bhatia, 2009). In fact, a study shows that doubling the number of four way intersections in an area will reduce

travel speed in the area by about 10%. Even though the reduced speeds will mean higher emissions by the same vehicle on the same trip, and increased local emission levels, the increase is not significant as compared to the overall decrease in emissions due to lower VMTs (Choi & Zhang, 2017).

Keeping the others factors such as demographics and density as is, getting people to switch modes is going to be a challenging job. People who have access to cars do not want to give up the luxury that it provides. Keeping those conditions in mind, car sharing is still an option to consider. In fact, high occupancy passenger vehicles are more efficient than buses even, due to the low ridership of transit vehicles (Cheng, Madanat, & Horvath, 2016). It may increase average household emissions as people who had low emissions previously due to them not owning a car now share the costs, but we still see a reduction in the overall levels (Martin & Shaheen, 2011).

4 EMERGING TECHNOLOGIES:

The increasing environmental and health costs due to the heavy transportation use has led to more research into the field of alternative vehicle technologies which aim at reducing pollution, traffic congestion, and increasing pedestrian safety. The first foray into such vehicles has been through the introduction of electric vehicles.

4.1 ELECTRIC AND HYBRID VEHICLES -

Electric vehicles (EVs) are considered good for the environment due to their negligible tailpipe exhaust gas emissions. They're even considered to be more environmentally friendly than public transportation modes when just the drive cycle is considered (Langbroek, Franklin, & Susilo, 2017). However, looking at it from a life cycle perspective, electric vehicles still produce plenty of greenhouse gases due to the electricity being sourced from fossil fuels. Until we move to a more sustainable way of producing electricity, a better alternative should be looked at.



Figure 1 - Hybrid Car. Source: http://i.telegraph.co.uk/multimedia/archive/02528/Toyota-Prius-Plugi_2528049k.jpg

This is where a hybrid vehicle comes into play. An HEV (Hybrid Electric Vehicle) consists of both an internal combustion engine and an electric propulsion system. The

vehicle's kinetic energy when decelerating charges the battery that can then be used up while accelerating. This aims to achieve better fuel economy. A study done on hybrid vs. electric trucks concluded that with the added bonus of the brake regeneration system and low manufacturing costs, hybrid vehicles tend to produce the least greenhouse gas emissions (Zhao et al., 2016).

Due to people's hesitation of adopting new technologies, especially when it comes to driving, hybrid is generally more popular among the crowd than electric vehicles. The shorter range and lack of charging stations at present gives more of an incentive to people to prefer hybrid vehicles over EVs. The social factor also plays into people choosing hybrid vehicles. The 'neighbor effect' leads to people adopting hybrid vehicles after watching their neighbors do the same. This leads to a subsequent technology adoption since early adopters of new technologies are higher (X. Liu, Roberts, & Sioshansi, 2017). The higher initial costs of electric vehicles also mean that there are lesser 'pioneer' and 'mainstream' buyers, with most of them belonging to high income households that can afford to experiment. Most pioneers prefer a Hybrid Electric Vehicle, followed by a Plug in Hybrid (PHEV), with the Battery Operated vehicles (BEV) being given last preference (Axsen et al., 2016).

It has been observed that users of Electric Vehicles tend to take significantly more number of trips as compared to non-EV users, with the vehicle use accounting for a larger percentage of the total travel distance as compared to before. In spite of the trip distances being shorter, not only does the increased use lead to an increase in energy consumption but also causes externalities such as congestion (Langbroek et al., 2017).

4.2 AUTONOMOUS VEHICLES -

The new emerging technology of Autonomous vehicles tends to resolve the limitations of non-autonomous EVs like access to charging infrastructure, charging time management, etc. (Chen et al., 2016). Automated or semi-automated vehicles will not only help relieve congestion but also increase fuel economy. A study conducted on vehicles equipped with fuel economy optimization systems (FEOS) found that the new technology consumed significantly less fuel in all conditions at the individual vehicle level, with gas savings upto 22-31% while accelerating, and 12-26% while decelerating (Wu et al., 2011). In fact, replacement of just 10% semi-automated vehicles into regular traffic has shown to reduce fuel consumption and pollution levels by 28.5% and 1.5-60.6% respectively, without affecting the general traffic flow rate (Bose & Ioannou, 2003). However, decreasing congestion and improving the overall traffic conditions may require market AV penetration upto 80%, as per a study conducted in downtown Austin. This number is greatly dependent on the network topology as well (Levin & Boyles, 2016).

Automated vehicles will also help reduce pedestrian fatalities on roads. Human errors will be reduced, as an AV's sensors cover the blind spots that human drivers usually have. The sensors will also calculate the distance from a pedestrian and time to wait for them to cross based on the human's activity. This will help reduce unnecessary wait times for pedestrians who may have already decided to not cross the road (Hashimoto, Gu, Hsu, Iryo-Asano, & Kamijo, 2016).



Figure 2 - Autonomous Vehicle Sensitivity. Source: <https://www.extremetech.com/wp-content/uploads/2014/09/self-driving-head-640x353.jpg>

There have been several studies conducted on how introduction of autonomous vehicles will change existing traffic patterns. It was found that wait times at intersections would reduce by 25% as compared to human drivers. Since the queue discharge pattern of a human driven vehicle would not transfer onto the AVs, it will help by making the traffic flow much smoother (Le Vine et al., 2016). However, no matter the level of intervention into the current traffic, VMT is likely to increase, just as in the case of EVs, by as much as 14% for US population aged 19 and older, leading to an increase in energy consumption and emissions(Harper et al., 2016). Which is why we need to find a way to come to a common ground between the emerging technologies to find the best way to reduce the impacts of the transportation sector on the environment.

Automated vehicles have quite a few social benefits to offer, ranging from increased mobility for the elderly and the disabled, to better use of land. For it to be adopted, people should be open to adopting the new technology. A survey conducted in Austin, Texas indicated that people see a lot of benefit to owning autonomous vehicles, with reduced crashes being indicated as the primary benefit. Their highest concern was failure of equipment. They respondents were told to choose between owning a semi-autonomous (level 3) vehicle, or an autonomous (level 4) vehicle. More than 80% choose to go for the second option, which is complete automation. This may be due to them finding more advantage in going hands free which would give them the opportunity to be involved in other activities during the trip, something that they would not achieve with semi-automation. Even the average willingness to pay (WTP) was much higher at \$7253 for a level 4 vehicle, as compared to \$3300 for a level 3 vehicle. It should be noted that this pattern was only observed with the younger generation. In contrast, older licensed drivers expressed less interest in the automation technology as they may not be interested in losing complete control the vehicle (Bansal et al., 2016).

If combined with the concept of shared hybrid vehicles, automated vehicles have the capacity to cause a tremendous shift in the way we plan cities. Ride sharing is already gaining popularity, with companies like Uber and Lyft providing us with more options. Uber has even introduced pooling, providing the car sharing service at decreased costs for customers, and at the same time reducing both VMT and emissions of the individuals using the service. A simulated model shows us that by introducing 700 SAVs (shared autonomous vehicles) into the system, we can reduce parking demands by up to 90%, although at the cost of sacrificing VMT, thus leaving more space to plan mixed

use, human oriented developments (Zhang et al., 2015). Another model run in the city of Austin, Texas shows us that a SAEV (shared autonomous electric vehicle) can replace anywhere from 3.7 to 6.8 privately owned vehicles depending on the vehicle range and charge capacity. The SAEV will be able to serve 96-98% of trip requests with average wait times of 7-10 mins. The calculated per mile cost is competitive enough to replace current manual car sharing services (Chen et al., 2016).

Apart from the technological barriers currently facing AVs, we need to overcome the regulatory issues as well. Creating policies for artificial intelligence is something that will take a lot of effort. Introducing sustainable measures to reduce emissions makes it even more complicated. Even though the technology is still under development, it's testing is already underway and chances are that automated vehicles will become much more common in the next decade. Effective policies need to be designed to regulate their use and reduce the externalities that they are sure to bring with them.

5 APPLICABILITY OF AUTONOMOUS VEHICLES —

Self-driving cars are not a far-off dream. Baidu plans to put its own vehicle on the roads by 2018 (Author:, Ng, Lin, Ng, & Transportation, n.d.). Even though there's time until driverless cars reach the status that regular automobiles have at present, large scale deployment is going to begin in the next decade. The table below gives an expected timeline of autonomous vehicle deployment.

Stage	Decade	Vehicle Sales	Veh. Fleet	Veh. Travel
<i>Available with large price premium</i>	2020s	2-5%	1-2%	1-4%
<i>Available with moderate price premium</i>	2030s	20-40%	10-20%	10-30%
<i>Available with minimal price premium</i>	2040s	40-60%	20-40%	30-50%
<i>Standard feature included on most new vehicles</i>	2050s	80-100%	40-60%	50-80%
<i>Saturation (everybody who wants it has it)</i>	2060s	?	?	?
<i>Required for all new and operating vehicles</i>	???	100%	100%	100%

Table 1 - Autonomous Vehicle Implementation Projections (Source: (Litman, 2014))

Before we can think of bringing autonomous cars onto our roads, there is a lot that we need to take care of. Autonomous vehicles would have a tough time working efficiently if the present state of transportation infrastructure and traffic on the roads stays the same. As self-driving vehicles are heavily dependent on electronic communication. Which means that traffic infrastructure like signals would be mandatory on a road if such vehicles are introduced on it. Another factor to be considered is increasing the predictability of a self-driving vehicle, which would mean making sure the roads are well maintained since even a small anomaly could throw off the car's algorithm.

5.1 CHALLENGES WITH INTRODUCTION OF SELF-DRIVING CARS:

It should be noted that most of the studies on autonomous cars have been conducted in highly developed countries, where traffic is well managed. If we take the example of a developing country like India, where traffic patterns are highly erratic, implementing a system of self-driving vehicles would be quite a challenge (Ghoshal, 2017). Not only is the traffic unmanaged, possibly rendering the highly controlled array of electronic sensors useless, but autonomous cars would have to encounter a variety of vehicles, most of which would be brand new to the testing environment of such a car.

A walk down a typical Indian road would show you that the roads have more two wheelers than four. Three wheelers like auto rickshaws are also present in abundance as they are one of the most used forms of public transportation in the country. You would also encounter bicycles, buses, trucks, and even plenty of cattle, on the same narrow two-lane road, and none of the above-mentioned vehicles would be driving in their lanes. The increased leeway present for the two wheelers due to them taking minimal space on a lane meant for large vehicles means that they have the freedom to move around as required by them to make sure their travel time is reduced. These are the kind of challenges that autonomous vehicles have not been equipped to deal with yet.

Despite it being harder to deal with such issues, these places are also the ones that would benefit the most if autonomous vehicles were, by chance, successfully implemented. India has recorded a total of 400 road accidents per day in 2015. The aim is to reduce this to at least half by 2020. India also has one of the highest recorded levels of air pollution in the world. Autonomous vehicles would not only reduce idle

traffic time (which takes up a big portion of road commute), but it would help increase car sharing, thereby also reducing the actual amount of vehicles on the road (Ghoshal, 2017).

The Indian government has already given the green flag to companies to test self-driving vehicles in the country (Arora, Mukherjee, 25, 2017, & Ist, n.d.). The hope is that the introduction of emerging technologies on a small scale, and then trying to integrate it into the main transportation system, might help improve the existing traffic condition as well. If autonomous vehicles were to successfully run in a country like India, it would be a win-win for both sides, with the technology being proven to not only handle even the worst traffic, but also making it much more systematic in the process.

6 SCOPING OUT AREAS IN ATLANTA —

There are many factors that can determine how successful autonomous vehicles will be in the future. The paper has discussed many of them so far. For our analysis, we will be taking a few of these into consideration and applying them to Atlanta's context. The factors that have been considered are:

- Population density
- Employment density
- Condition of the major roads in the city

The first two have been selected to give an idea of what areas in Atlanta are most travelled to and from. For the third we only consider the major roads, assuming that they have all the amenities required to run an autonomous fleet like sidewalks, adequate number of lanes, etc., and calculate the number of traffic signals present per mile of the road. This would also serve as a good estimate of how many intersections there are along the road.

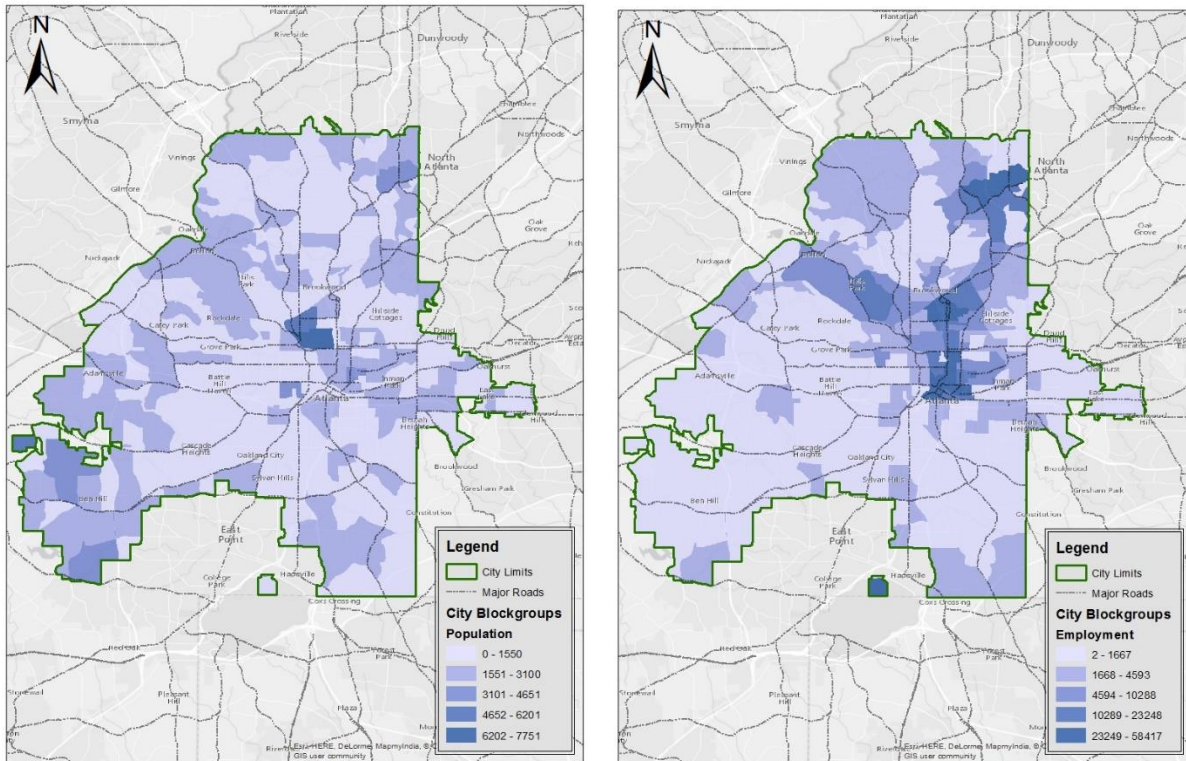


Figure 3 - Population and Employment Density in the City of Atlanta

From the above images, we can see that most of the population and employment density in the City of Atlanta is located in the central Midtown/Downtown region and Buckhead in the north east. The population projection also shows scattered numbers in the peripheral region. In fact, this could be backed up by the presence of suburbs around the periphery of metro Atlanta. The areas in darker blue are the ones that we hope to be able to establish a link between, and we will do that by analyzing the roads present in the area.

From Figure XXX on the left, we can see at first sight that the roads that show the maximum concentration of traffic signals are the ones that connect Downtown to

Buckhead. Calculating the signal density on these roads and selecting the ones that show most promise gives us the result as shown in Figure XXX on the right.

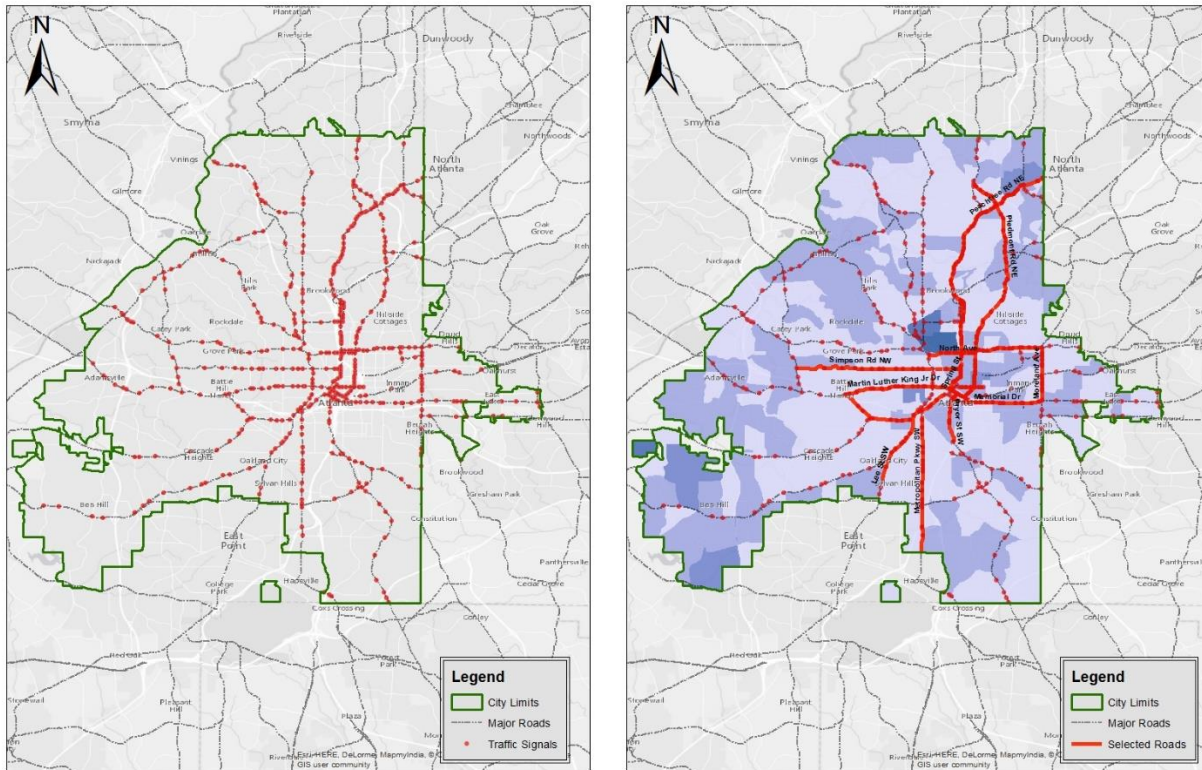


Figure 4 - Traffic Signals (Left) and Final Results (Right)

As expected, the roads that were selected by the considered criteria are roads that run north to south like Peachtree and Piedmont Road. A few streets that run perpendicular, i.e, east to west, like North Avenue and Martin Luther King drive also showed up in the results.

North Avenue is already being considered as a potential candidate for a driverless smart corridor owing to it being a major connector between Georgia Tech and Ponce City Market. In fact, the testing of the first autonomous cars in Atlanta may begin here.

7 CONCLUSION —

The future of transportation is fast approaching. Autonomous vehicle testing has already begun in many parts of the country, supported by large corporations such as Google and Uber. But there are many obstacles that are going to arise in the process. Multiple studies have shown that autonomous vehicles will not reduce, but rather increase traffic on the roads. It may reduce land use patterns by changing the parking requirements but it most definitely will not aid in increasing density unless there are strict zoning regulations enacted to go along with the new technology.

One obvious way to take care of the concerns that accompany a new technology is combining it with other tried and tested methods. This is where the hybrid and shared vehicle systems will be useful. If we combine these to help create a new way of transit, dubbed Shared Hybrid Autonomous Vehicles, there is a very good possibility that the aims of reducing pollution and traffic on the roads, increasing public transit use and providing access to the disadvantaged groups will successfully become a reality.

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